NPS-OC-98-002PR

# NAVAL POSTGRADUATE SCHOOL
## Monterey, California

**Report on the Office of Naval Research**
**International Workshop**
**on Shallow Water Acoustics**
**San Francisco, CA**
**8-9 December 1997**

by

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March 1998



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This report was prepared for and funded by the Office of Naval Research under contract Number N0001498WR30091.

 This report should be cited as: Naval Postgraduate School Tech. Rept., NPS-OC-98-002PR.

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# Report on the Office of Naval Research International Workshop on Shallow-Water Acoustics, San Francisco, December 8-9, 1997

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March 1998

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# Executive Summary

Under the sponsorship of the Office of Naval Research, an international workshop on shallow water acoustics was held in San Francisco on December 8-9, 1997. The purpose of this two-day workshop was to investigate the scientific, engineering and logistic rationales that might form the basis for a collaborative international experiment in an Asian sea. Attended by 42 participants from Australia, China, India, Japan, Korea, Russia, Singapore, and the United States, the first day of the workshop featured a series of short presentations by the representatives of the different countries on their research interests, and what resources they might be able to contribute to a collaborative experiment if it were to take place in 1999. On the second day, a group discussion on potential sites, research vessels, surveying and moored equipment, and scientific issues was carried out.

This workshop shows that acoustics clearly unifies many diverse interests of ocean scientists; geological, physical, biological and chemical. Each of these has distinct roles in the propagation of sound energy in the ocean, and inversely acoustical techniques provide powerful means for understanding properties and processes in each of these areas of ocean science. Bottom interaction acoustics is one of the many good examples: Acoustical techniques are the only efficient means of exploring the composition and structure of the sea floor over any sizable area. Inversely the interaction of acoustic energy with the bottom is one of the most significant factors in determining the acoustic wavefield in shallow water. Bottom scattering and reverberation and sub-bottom inversion techniques were identified as principal interest by several of the participants.

Nearly all the participants expressed an interest in the possible collaborative experiment and had resources to contribute. While a site for the experiment was not selected at the workshop, several locations were proposed and discussed, with the majority of the participants favoring the South China Sea, East China Sea and Yellow Sea. The amount of equipment available to the participants was formidable. It was clear that a very well designed experiment could be mounted, an experiment which would provide a wide range of observations on space and time scales that would be difficult for any individual country to achieve. It was agreed that a second workshop would be held in June 1998 to focus on the development of a detailed experimental plan.

# 1 Introduction

The Office of Naval Research (ONR) sponsored a workshop at the Hyatt at Fisherman's Wharf, San Francisco, on December 8-9, 1997 to establish the scientific, engineering, and logistic rational for an international shallow-water acoustics experiment to be conducted in an Asian coastal zone. Participants were invited from Australia, China, India, Japan, Korea, Russia, Singapore, and the United States. This international workshop follows a continuing evolution of collaboration with China. The first was an ONR-sponsored conference between U. S. and Chinese scientists, held in December 1995 at the Naval Postgraduate School (NPS) in Monterey, California[1]. There were approximately ten participants each from China and the United States. The discussion centered around possible joint experiments in shallow-water acoustics. That conference was followed by a joint U. S.-China experiment in the central Yellow Sea in August 1996. This pilot experiment was sponsored by ONR and the Chinese Academy of Sciences (CAS), and the focus of that experiment was on internal wave-acoustic interaction and bottom reverberation. ONR and CAS also jointly sponsored an International Conference on Shallow Water Acoustics in April 1997 (SWAC'97) in Beijing[2]. SWAC'97 was attended by 100 plus participants and it expanded the dialog and scientific exchange to include other countries in the Asian Pacific rim. These were the building blocks that led up to this workshop.

The San Francisco workshop was organized by Dr. Chiu of NPS and Dr. Denner of EOS Research Associates. After brief administrative remarks and introduction of the participants, Dr. Simmen of ONR defined the goals and objectives of the workshop and Dr. Livingston of ONR outlined the programmatic directions of the ONR Ocean Acoustics Program. This was followed by the presentation of a Strawman (example) of Scientific Issues by Dr. Chiu of the Naval Postgraduate School (NPS). After Chiu's presentation, representatives of each country or laboratory presented and discussed their research interests, experimental capabilities, and recommendations for a possible experiment. The workshop was concluded with a group discussion on potential sites, research vessels, surveying and moored equipment, and scientific issues.

This report summarizes the presentations, discussions and findings of the workshop. The report has the following outline: The workshop goals and objectives and the programmatic directions of the ONR Ocean Acoustics Program, as stated by Simmen and Livingston, are summarized in Section 2. Section 3 recaps Chiu's presentation on a Strawman of Scientific Issues. Section 4 reviews the presentations by the representatives. Input from the participants on scientific objectives and sites of interest as well as available and needed equipment are presented in Section 5 in tabular form.

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[3] Chiu, C.-S. and W. W. Denner, "Report of the Office of Naval Research USA-China Conference on Shallow-Water Acoustics, December 19-21, 1995," NPS Technical Report NPS-OC-97-001, January 1997.
[2] "Proceedings of SWAC'97" (Editors: R Zhang and J. Zhou), in press.

Conclusions of this report is given in Section 6. The agenda of the workshop is provided in Appendix A. An attendee list can be found in Appendix B.

## 2 Goals and Objectives

Dr. Simmen opened the Conference by stating that the long-term objective was to have a collaborative international experiment in 1999. The goals of this meeting were to establish the initial scientific goals, identify possible experimental sites, explore the international capabilities and interest in participation, and to discuss some of the possible logistics issues. Simmen welcomed the participants, acknowledged that any potential experiment would likely be multi-disciplinary in nature, and that ONR was represented by program managers from Ocean Acoustics, Marine Geology and Geophysics, Physical Oceanography, and Signal Processing. He also reviewed the developments in Asian-American collaborations that lead up to this workshop.

Drs. Simmen and Livingston outlined the programmatic directions of the ONR Ocean Acoustics Program. These involve theoretical and experimental projects addressing the physics of the generation, propagation, and scattering of sound in the ocean environment. Their current plan is to fund periodic major field experiments in each of the following areas:

Shallow–water acoustics
High-frequency acoustics
Long-range propagation

These acoustics experiments will be performed with detailed environmental measurements. Increased international collaboration/cooperation is desired with Asia, Europe and FSU (Russia). They noted that there was an increasing emphasis on shallow water and identified some of the key investigators and institutions currently sponsored by ONR who are working in shallow water acoustics.

## 3 Strawman (Example) Scientific Issues

Dr. Chiu presented a Strawman of Scientific Issues to lead off the discussions. Chiu has participated in several ONR-sponsored, multi-institutional, integrated acoustic and oceanographic field studies in continental shelf-slope transition regions. In such a region, the propagation of sound can be significantly affected by a variety of complex oceanographic factors such as:

- A meandering shelf-slope or shelfbreak front
- The associated eddy field
- Mixing processes

- Internal tides and large-amplitude internal solitary wavepackets
- Variable bathymetry and sediment structure
- River outflow and sedimentation
- Biological activities

Using results from the 1992 Barents Sea Polar Front Experiment, the 1995 Shallow-Water Acoustic Random Media Experiment and the 1996 and 1997 Shelfbreak PRIMER Experiments, Chiu reviewed some of the unique aspects of the ocean variability in a shelf-slope environment and illustrated how they might perturb the sound field.

Athough each of these previous field studies was carried out at a different geographical location and focused on a different set of scientific issues, they shared some common characteristics in their settings. In all of these cases, there was always a coastal front with moderate to strong gradients separating cold and warm water masses, no major river outflow in the surrounding area, and a steady on/off-shore tidal flow generating shoreward propagating internal tides through a lee-wave mechanism. Additionally, all of these previous shelf-slope studies have used sound sources with frequencies less than 500 Hz, considered almostly exclusively upslope or downslope propagation geometries, and concentrated on the measurement of the vertical properties of the sound field only. Thus, to expand from the present knowledge base, Chiu suggested that it is worthwhile to consider the relatively untouched, yet important topics in the next shallow-water acoustic experiment. To name a few, the unexplored topics include the physics of sound transmission through multiple coastal fronts, the acoustic effects of a discharge river plume and the river injected sediments, the characterizations of acoustic fluctuations due to internal tides and internal waves that are generated by different mechanisms, and joint sediment and water column inverse schemes. Chiu went on to suggest that it is desirable to focus on the horizontal properties of the sound field such as azimuthal coupling and horizontal coherence, along-shelf transmissions, a broader band of frequencies (e.g., 50-4000 Hz), in addition to vertical properties in cross-shelf geometries.

The Asian Pacific rim offers a variety of research opportunities in different settings (South China Sea, East China Sea, Yellow Sea, Korean Straits, Sea of Japan, etc.). Chiu used a site on the northern continental shelf of the South China Sea (SCS), south of Hong Kong (see Figures 1 and 2), as an example to illustrate some of the potential opportunities. In this region, oceanographic processes contributing to acoustic variability include a shelfbreak front (separating shelf water from slope water of Kuroshio origin) and the discharge plume of the Pearl River, both of which may exhibit rapid changes in thermal structure and water properties due to tides (including internal tides and high frequency internal solitary waves), frontal meandering and instability, and surface forcing (especially wind forcing on the river discharge plume). The bottom type is dominated by river transported silts, and bottom composition, structure and roughness also affect shallow-water sound propagation. An acoustic experiment there could also benefit

greatly from several on-going or planned oceanographic measurement programs including a funded ONR DEPSCOR experiment on the south China continental shelf (headed by Dr. Pettigrew of the University of Maine), Taiwan's Luzon Straight Flow Monitoring Program, and the International SCS Monsoon Project. Thus, the location offers oceanographic and acoustic conditions that are uniquely different from the previous study areas, and by leveraging with the other relevant programs, it would be possible to address multiple objectives with a limited set of equipment.

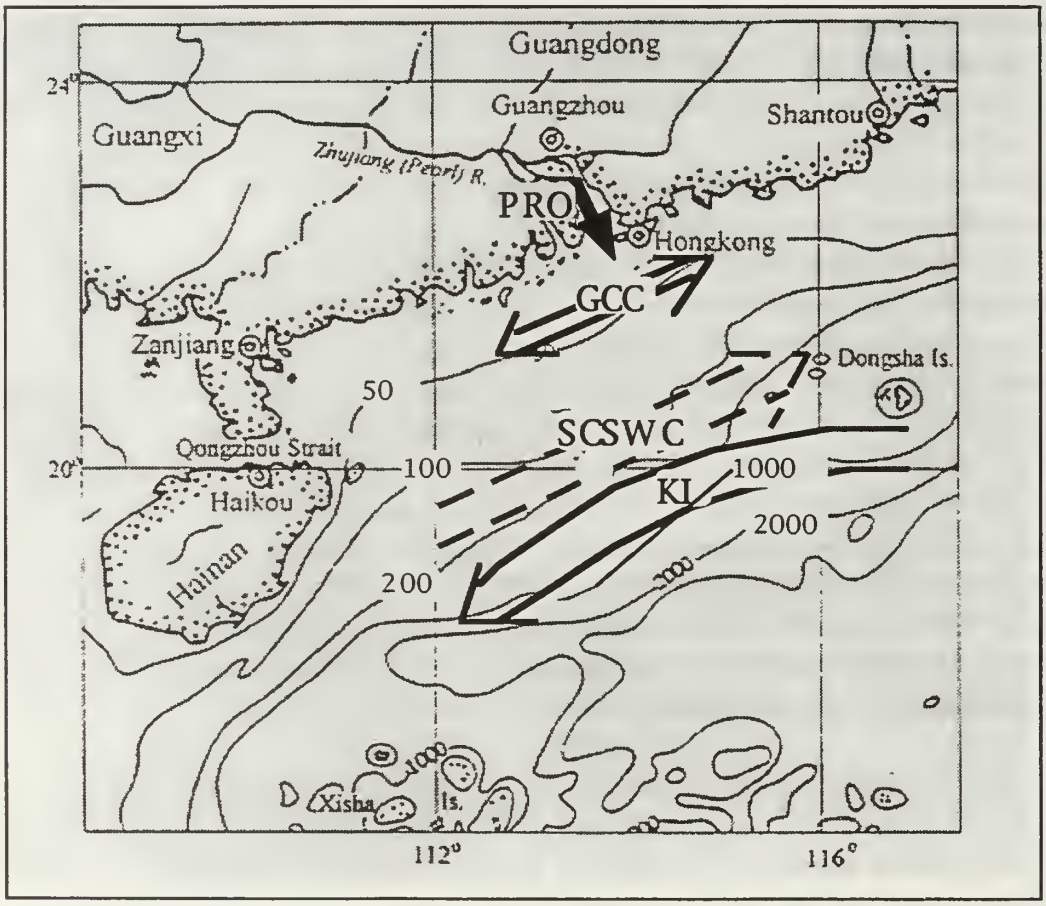


Figure 1. A schematic drawing of the coastal currents over the continental shelf and slope off southern China (a candidate experimental area). The Pearl River outflow (PRO), Guangdong Coastal Current (GCC), the South China Sea Warm Current (SCSWC) and Kuroshio intrusion (KI) are indicated. The GCC reverses seasonally with the monsoon winds. The existence and vertical structure of the SCSWC are subjects for investigations.

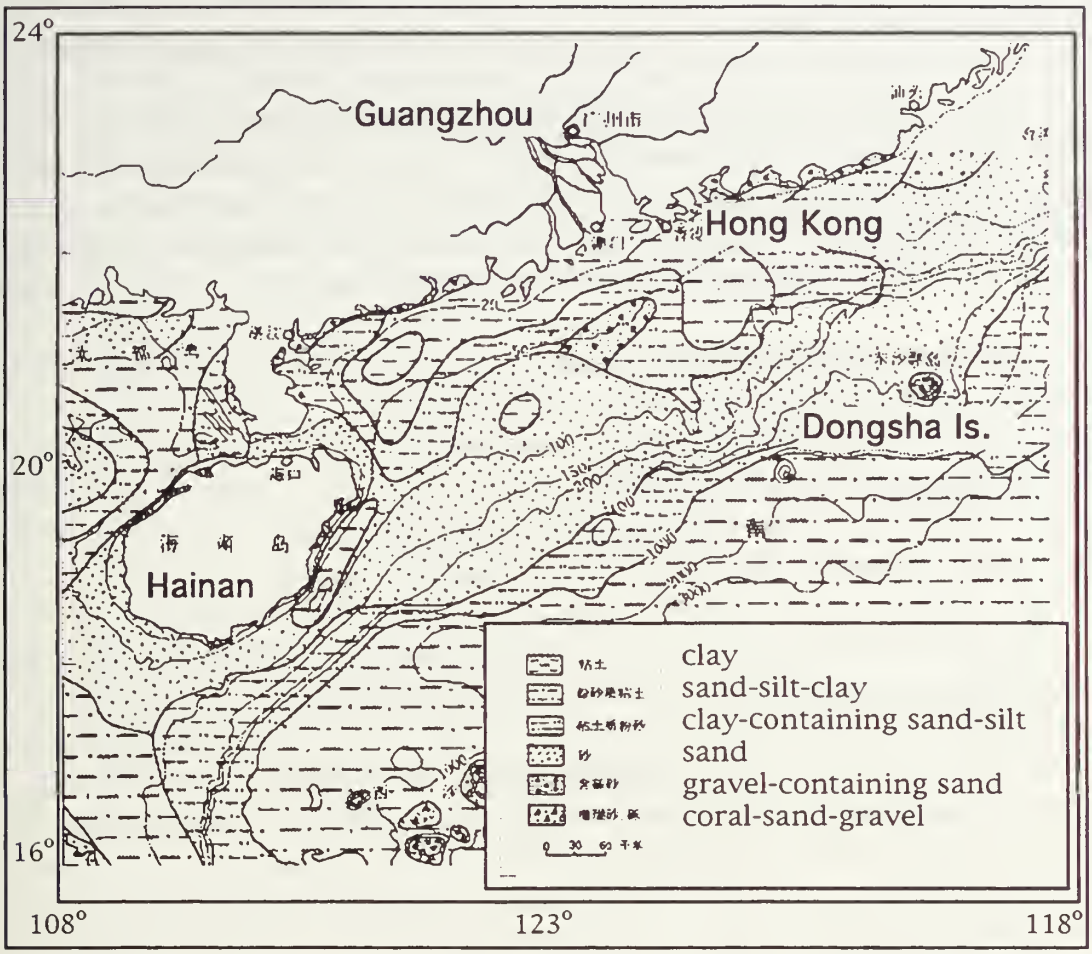


Figure 2. Grain size patterns of surficial sediments in northeastern part of the South China Sea (after Su et al., 1989[3]). This candidate experimental area has various sediment types that exhibit bands, with boundaries roughly parallel to the isobaths.

Chiu concluded by pointing out that ocean acoustics now provides significant potential for understanding the physical oceanography of a region. Acoustic sensing methods have significantly contributed to our understanding of shelf dynamics, mixing, biological and sedimentary processes, internal tides, and internal waves for example. Alternately, a better understanding of the physical oceanography has led to a better understanding of the acoustics.

[3] Su Guangqing, Fan Shiqing and Chen Shaomou et al., "The Sedimentary Atlas of Northern and Central South China Sea," Guangdong Science and Technology Press, China, 1989.

# 4 Presentations by Representatives

## *4.1 Prof. Renhe Zhang, Director, National Laboratory of Acoustics, CAS , China*

Prof. Zhang was instrumental in the development of the joint U. S.-China collaboration in ocean acoustics leading up to this workshop. He helped organize and participated in the Monterey workshop, the Yellow Sea Experiment, and the Beijing Conference. He continued to express China's desire for further collaborative efforts and outlined a wide range of Chinese research interest in ocean acoustics:

- Acoustic inversion of bottom parameters
- Frequency and depth dependencies of reverberation
- Vertical correlation and directionality of ambient noise
- Acoustic interactions with internal waves
- Acoustic interactions with the Kuroshio in the East China Sea
- Relevant measurements and research on the ocean environment

The Chinese bring much to the table for any experiment in the seas of China. Not only do they have a natural interest in their territorial waters, but substantial previous field experience, instrumentation and equipment, several research vessels, and a number of important logistics facilities. Zhang listed the equipment which belongs to his laboratory. For acoustic measurements, his laboratory has several electronically controlled broad and narrow-band sound sources covering the 300 Hz-to-9000 Hz frequency band, an electric spark source, and telemetered and *in situ* recording vertical receiving arrays. For environmental measurements, they have three thermistor chains, 2 Acoustic Doppler Current Profilers (ADCPs), a CTD, and a sub-bottom profiler. Zhang indicated several possible sites for experimental work, but thought that it would be difficult to obtain Chinese government approval for a collaborative experiment in the northern shelf of the South China Sea, such as the area discussed earlier by Chiu.

## *4.2 Prof. Zengdi Pan, Deputy Director, First Institute of Oceanography, SOA, China*

Prof. Pan elaborated on the interests and previous work of the First Institute of Oceanography, State Oceanic Administration (SOA). His institute has a significant amount of oceanographic capability. This includes research ships, modern oceanographic equipment and satellite remote-sensing data processing facilities. His Institute has carried out internal wave research since 1955. From 1995 they have conducted studies of the circulation in the Yellow Sea, and have a continuing interest in continental shelf dynamics in the Yellow Sea.

Pan outlined some of their main research topics and interests:

- To carry out comprehensive field experiments using different acoustic and oceanographic measurement systems
- Data processing and inversion techniques
- Applications of satellite remote sensing particularly SAR
- Internal waves, both observation and theoretical

He also indicated that they have a continuing interest in the Yellow Sea, but mentioned several other areas where they would be interested in working. These included, the Luzon Straits, the shelf areas of the South and East China Sea, and the Sulu Sea.

### *4.3 Dr. Zinping Zhao, Deputy Director, Institute of Oceanography, CAS, China*

Dr. Zhao outlined their research interests in the Yellow Sea, but also expressed an interest in participating in a joint experiment in other areas such as the shelf areas of the East and South China Seas. He specifically expressed interest in:

- Time and spatial distributions of the inversion thermocline in the Huanghai Sea (Yellow Sea) and their acoustic structure
- The intensity, time and spatial variation of the environment and biological noise in the Huanghai Sea
- The structure and characteristics of the thermocline in the Huanghai Sea
- The internal tide in the northern part of the South China Sea

He indicated that there are oil platforms in the northern South China Sea from which oceanographic measurements had been collected in the past. His institute would be interested in conducting research in the East and South China Seas in the areas that have been identified by Chiu and Zhang.

### *4.4 Dr. Iwao Nakano, Head of Tomography Group, JAMSTEC, Japan*

Dr. Iwao Nakano said that JAMSTEC's interest was primarily in deep water. They have developed acoustic tomography systems intended for the real-time monitoring of ocean circulation. They have five 200-Hz and three 400-Hz tomography transceiver systems, and have deployed some of those systems in the Kiroshio Extension region.

### *4.5 Prof. Arata Kaneko, Hiroshima University, Japan*

Prof. Kaneko expressed a strong interest in:

- Monitoring and forecasting of eddy-included velocity fields in the coastal ocean
- Long-term monitoring of strait through flows (International Strait Program)
- Construction of much cheaper tomography systems

He outlined some of the research groups in Japan that work in ocean acoustics, and discussed the ongoing collaborative efforts in the Korean Straits with the Korea Ocean Research and Development Institute (KORDI). He also discussed a joint experiment with the Second Institute of Oceanography, SOA of China in 1996 to study the Western Pacific subtropical gyre using a towed ADCP system.

### *4.6 Prof. Kiyoshi Suyehiro, University of Tokyo, Japan*

Professor Suyehiro had some very brief remarks regarding his research interest. He has a side scan sonar system which could be used in a collaborative experiment of interest.

### *4.7 Prof. Jungyul Na, Hanyang University, Korea*

Representing KORDI, the Agency for Defense Development (ADD), the University Acoustic Research Consortium (UARC), and the Acoustical Society of Korea (ASK), Prof. Na provided an overview of some of Korea's research interest and recent work. He discussed the regional circulation and coastal processes in waters surrounding Korea. He described experimental results from recent and ongoing oceanographic studies in areas of possible interest for collaborative studies. One such study was a broadband tomography experiment conducted east of the Korean Peninsula to investigate the spatial temperature structure of a large warm eddy. These measurements could provide significant baseline data in preparing for further studies in the area.

### *4.8 Dr. Bishwajit Chakraborty, Asst. Director, National Inst. of Oceanography, India*

Dr. Charkraborty discussed the organization and research activities of the National Institute of Oceanography (NIO). This is a comprehensive oceanographic center involved in a wide variety of oceanographic studies, primarily in the Indian Ocean. He discussed some of their recent interests in ocean acoustics, that include bottom scattering, tomography and techniques for assessing living marine resources.

### *4.9 Dr. Victor Akulichev, Director, Pacific Oceanological Institute, Russia*

After giving a brief introduction of the members of the Russian delegation and indicating that his institute had been in existence for 25 years this year, Dr. Akulichev discussed some of their tomographic studies in the North Pacific off the Kamchatka Peninsula, as well as some of the acoustic research facilities operated by his institute near the border with North Korea. He suggested that these facilities might be used for collaborative research, and described possible tomographic measurements of regional global warming impact on the Sea of Japan from this site. He indicated that his institute had a wide variety of acoustic sources available that could be used in a collaborative

experiment. He described a high-power, low-frequency sound source for long range global acoustic monitoring. He also indicated that his institute had a long history of work in the seas of China, and had significant data holdings that could be made available to support collaborative efforts.

### *4.10 Prof. Boris Kuryanov, Shirshov Institute, Russia*

Prof. Kuryanov discussed the research conducted by his institute on mapping small or intermediate-scale ocean perturbations caused by deep-water internal waves and tides using high-frequency tomographic transmissions, a technique which he referred to as "local" acoustic tomography. The frequencies used were greater than several kilohertz in contrast to the 75-to-400 Hz frequencies typically used in large-scale tomography. He described the hardware of this high-frequency tomographic system. It consisted of deep-water autonomous acoustical bottom buoys with vertical receiving arrays. He mentioned potential collaborative efforts with Chinese Scientists to modernize/modify four of these acoustical buoys for shallow-water tomographic work.

### *4.11 Prof. Eng-Soon Chan, Head, PORL., National University of Singapore*

Prof. Chan discussed the organization and interest of the Physical Oceanographic Laboratory (PORL) at the National University of Singapore. The PORL interests included a wide variety of marine hydrodynamic processes, mixing and sedimentation, pollution, and biological interactions in tropical waters. As a part of Singapore's Tropical Marine Sciences Initiative (TMSI), one of their goals is to create a coupled physical, chemical and biological three-dimensional model of the tropical water column. They are using numerical models in conjunction with data sets in such a development, with an initial focus on the monitoring, modeling and prediction in the Strait of Malaca. A variety of modern oceanographic instrumentation is available for measurement projects.

### *4.12 Dr. John Potter, Head, ARL, National University of Singapore*

The Acoustics Research Laboratory (ARL) of the National University of Singapore is another component of the TMSI. Dr. Potter indicated that his lab's focus is on high frequency imaging and acoustical oceanography. The acoustical oceanographic investigations are supported by various types of remote-sensing measurements such as synthetic aperture radar (SAR), optical, and infrared (IR) imagery. Dr. Potter outlined their research philosophy as a general interest in acoustic oceanography physics rather than a special-case scenario, meaning that it encourages basic research that can be generalized to many shallow-water regions, address broader issues, and extend our current understanding with new techniques applicable to rapidly varying shallow-water environments. He suggested that high-frequency shallow-water tomographic inversion and broadband multi-scale temporal experiments be a part of collaborative efforts to extract the relevant oceanographic and seabed parameters simultaneously. His lab has

some substantial instrumentation and data processing assets that could be brought into the proper collaborative experiment.

### *4.13 Dr. Steve Ramp, Office of Naval Research, USA*

Dr. Ramp used the Shelfbreak PRIMER field study off New England as an example of a high-quality, coupled physical oceanography and acoustics experiment. The experiment had a number of high-resolution observational components; satellite remote sensing, towed SeaSoar, acoustic tomography and a moored array of oceanographic sensors. The experiment was design to investigate the variability of the shelfbreak front and its influence on sound propagation from the continental slope to the continental shelf.

The strawman site presented by Chiu has some similarities to the Shelfbreak PRIMER site, but with multiple frontal structures forced by seasonal monsoon winds and the outflow of the Pearl River, a point source producing a volume of fresh water approximately equal to the outflow of the Mississippi River. Ramp thought that this would make an excellent site to add to our understanding of shelf dynamics and shelf acoustics. He suggested an intensive experiment (15-20 days) which would sample high frequency dynamics of the physical environment. He thought that perhaps the winter might be the best season because of the more intense dynamics brought about by the intrusion of the Kuroshio water into the South China Sea, but recognized that storm waves might make a winter experiment more difficult than a summer experiment.

### *4.14 Dr. Tony Liu, NASA Goddard Space Flight Center, USA*

Dr. Liu provided an overview of remote sensing activities in China, describing downlink sites for visible IR and SAR satellites. His talk focused primarily on the application of SAR imagery to the study of internal waves, and compared some of the satellite SAR images to modeling results. He discussed two types of internal waves (depression waves and elevation waves), and he provided a comparison of the internal wave characteristics in four areas, New York Bight, Yellow Sea, East China Sea and South China Sea

Liu showed several example SAR images of internal waves in the South China Sea and Yellow Sea. Some images showed very long internal wave features (amplitude greater than 100 m and 300 km between crests) that entered through the Luzon Strait impinge on the shelf north of Dongsha Island and approach Hainan Island. He also showed several images with internal wave features and ship wakes from the Yellow Sea and East China Sea. He pointed out the need for in-situ measurements to validate SAR observations and models.

### *4.15 Dr. Jixun Zhou, Georgia Institute of Technology, USA*

Dr. Zhou discussed his interests in shallow-water acoustics. They include mode coupling, long-range reverberation, small-angle bottom scattering, sea-bottom acoustic property inversion, and signal time/space coherence. He reviewed some of the oceanographic features of the Seas of China; currents, fronts, and internal waves. He suggested three possible experimental sites: an area off the southwest coast of Korea, the South China Sea near Dongsha Island, and an area on the shelf southwest of Vladiostok where Russian scientists have conducted some experiments. Zhou also discussed a novel transmitting array, which could be used to excite specific normal modes in the water column. The sources in the array are PZT capped cylinders, with a resonance frequency of 13 kHz and a broadband response. These sources can be formed into clusters (six individual sources) resulting in a cluster source level of 178 dB re 1μPa, which in turn could be arrayed in the water column resulting in an array level of 210 dB re 1 μPa at 1kHz. There are 280 individual sources available.

### *4.16 Dr. Marshall Orr, Naval Research Laboratory, USA*

Dr. Orr reviewed the recent interest of his group at the Naval Research Laboratory (NRL). These are:

- Propagation in Random Media
- Surface and bottom reverberation
- Shallow water ambient noise
- Bubble generation and properties

He discussed some of their recent involvement in shelf experiments, and some equipment that they could bring to the experiment if they were to participate. Orr suggested that he would prefer a site in the Yellow Sea off the West Coast of Korea or an East China Sea site southwest of Korea.

### *4.17 Dr. Peter Worcester, Scripps Institute of Oceanography, USA*

Dr. Worcester reviewed some of their recent experimental results from the Strait of Gibraltar. The experiment was designed to test the feasibility of acoustic approaches to monitoring transport in the Strait, and to see if they could understand the acoustic propagation in the complex environment of the Strait. The measurements showed that using reciprocal transmission the flow and temperature structure could be mapped over time. Worcester recommended that any experiment planned for the Seas of China should be simple enough to have a high probability of success, and generate results that could be generalized to other areas.

### *4.18 Prof. Tok Yamamoto, University of Miami, USA*

Dr. Yamamoto discussed the importance of scattering in shallow water acoustics. He provided examples of the contributions made by the surface, volume and bottom, both in a forward and backscatter geometry.

### *4.19 Dr. William Kuperman, Director, Marine Physical Laboratory, USA*

Dr. Kuperman provided a brief overview of the current acoustics interests of the Marine Physics Laboratory (MPL). These are:

- Physics-based signal processing in shallow water
- Ambient noise and environmental inversion
- Self adaptive systems and focalization
- High frequency shallow water acoustics and underwater acoustic communications
- Nearshore (10-20m) acoustics and bioacoustics

MPL has a substantial amount of underwater acoustic instrumentation that could be available for an experiment in the Seas of China.

### *4.20 Dr. Robert Spindel, Director, Applied Physics Laboratory, USA*

Dr. Spindel acknowledged that his laboratory had participated in the joint U.S./China experiment in the Yellow Sea. He reviewed some of the current underwater acoustics and oceanographic interests of his laboratory. The acoustic interests include:

- Volume scattering and reverberation (100Hz to 5 kHz)
- Bottom and surface scattering (5 kHz to 500 kHz)
- Acoustic and bubble interactions (20 kHz to 100 kHz)
- Small scale volume fluctuations (20 kHz – 50 kHz)
- Acoustic tomography

The oceanographic interests include:

- Flows over sills
- Turbulent dissipation
- Aerosol formation and gas transfer through the sea surface
- Geo-acoustic sediment properties and acoustic inversions

Spindel also reviewed some underwater acoustics equipment available at APL that could be used in a shallow-water experiment.

### *4.21 Dr. Lou Goodman, Office of Naval Research, USA*

Dr. Goodman reviewed some of the current programs in physical oceanography being supported by his office at ONR. These include:

- A five-year program in the Sea of Japan which started in FY98
- The Littoral Internal Wave Initiative (LIWI)
- Coastal mixing and optics
- Synthetic Aperture Sonar
- Flow through straits

He indicated that both ONR and NRL are supporting work on numerical models of the Yellow Sea and South China Sea. He pointed out that additional information on the ONR Physical Oceanography programs could be found on their internet website.

### *4.22 Dr. Yeli Yuan, Director, First Institute of Oceanography, SOA, China*

Dr. Yuan gave a talk that focused on the utilization of satellite remote sensing data in conjunction with models to invert for ocean dynamics. He showed some imagery and examples dealing with the mapping of internal waves and bathymetry.

### *4.23 Dr. James Lynch, Woods Hole Oceanographic Institution, USA*

Dr. Lynch used the recent SWARM and Shelfbreak PRIMER experiments to provide the background for discussing a list of measurement and scientific issues that had been mentioned or should be addressed in future shallow-water acoustics experiments. He recommended that there is a need for future experiments to consider the following:

- Horizontal array performance
- Wider bandwidth signal transmissions than previously used
- Longer data time series than previously measured
- Multiple source depths
- Diversity of along and across front transmissions
- More source/receiver ranges
- More signal diversity
- Bottom interaction measurement techniques
- Ambient noise studies
- Reverberation studies
- Fractalization schemes
- Optimizing sampling strategies

Lynch continued by listing some of the scientific issues that need further investigation in shallow water. These include

- Internal wave forcing
- Internal wave dissipation
- Fine structure and high frequency acoustics
- Eddy flux onto the shelf
- Processes at the foot of fronts
- Interaction of the wave and current fields
- Sub-bottom reflections
- Fish distribution and scattering

Lynch closed with the following remarks:

- Combined data sets are extremely valuable
- Physical oceanography, geology and geophysical processes are complex and adequate sampling and data analysis will always be necessary to improve our understanding
- Everyone has their favorite experimental site, but it is important to look at others

### *4.24 Dr. Joe Kravitz, Office of Naval Research, USA*

Dr. Kravitz, who heads the Geology and Geophysics program at ONR, provided some remarks to set the geological framework for shallow water acoustics. He explained that a systematic characterization of the sediment/water interface, sub-bottom structure and sediment compositions is required to achieve a thorough understanding of sound propagation in shallow water. The techniques which Kravitz recommended for measuring the bottom parameters are listed below:

- Techniques for measuring the surface roughness – sediment/water interface:
  - High-resolution multi-beam systems
  - Bottom photography
  - Tripod systems
- Techniques for measuring the shallow sub-bottom structure:
  - Chirp sonar (0-30m)
  - High resolution multichannel (0-100m)
- Techniques for measuring sediment composition/properties:
  - Cores and borings
  - Bottom towed magnetometers
  - Conductivity probes

### *4.25 Dr. Vladimir Shchurov, Head, Laboratory Of Ocean Noise, POI, Russia*

Dr. Shchurov proposed the following interesting topics for the collaborative experiment:

- Mechanism of the generation of acoustic noises in a coastal zone and its dependence on hydro-meteorological conditions
- Coherent and diffuse components of the acoustic noise field in a shallow sea
- Influence of the internal waves field upon the scalar-vector characteristics of acoustic fields
- Interaction of energy fluxes of noise and signal coming from deep open ocean in a shelf zone
- Influence of a bottom relief upon the formation of energy fluxes of bottom sediments
- Estimation of the impedance and structural peculiarities of bottom sediments
- Creation of statistical models and digital simulation of scalar-vector characteristics of noise and signal acoustic field in a fluctuating shallow-sea environment

He went on to describe the instrumentation that constitute his "scalar-vector method", involving simultaneous measurement of four field variables, the particle velocity vector (three components and the mean of the particle velocity), and the acoustic pressure.

### *4.26 Prof. Vladimir Bulanov, Head, Physical Acoustics Lab, IMTP, Russia*

Prof. Bulanov of the Institute of Marine Technology Problems (IMTP) discussed some of his interests. They include:

- Acoustical monitoring of bubbles (both in the surface layer and near the bottom)
- Sound scattering by plankton to estimate the plankton concentration and detect spatial variations
- Investigation of the nonlinear parameters

He showed some of the data he had collected and the instrumentation he used in his studies.

The participants identified a substantial amount of facilities, equipment, and other resources, which has been summarized in Table 4.1 of this report. In most cases the participants indicated that they wanted to participate in an experiment and that their resources would be available for use.

# 5 Potential Sites, Equipment and Experimental Objectives

On the second day of the workshop, a group discussion on potential equipment, platforms, experimental objectives and site options was carried out. In an effort to organize the information from as many delegates as possible, we asked each participant to prepare a brief summary which would include the following information:

- Name and affiliation
- Research topics of interest
- Preferred location(s) for field program
- Facilities, equipment and resources that might be available for the joint experiment

Not every participant responded, some responded but neglected to put their name on the sheet, and some of them responded as a group. We have attempted to abstract and summarize the information contained in their responses in Table 1.

Table 1 shows several interesting facts worthy of note. The first is that the participants showed enthusiasm for a joint experiment by outlining the scientific issues they would like to investigate. Furthermore, they identified the regions where they would like to see the experiment take place. Several possible sites were identified. These include the South China Sea, East China Sea, the Yellow Sea, the Straits of Korea, and the Sea of Japan. However, we think most significant is the list of resources the collective group could bring to a collaborative experiment in these waters. This is truly impressive. The collective list of people, ships, facilities, and equipment would probably be impossible for any single country to field in a shallow water experiment. We believe this aspect of the international nature of the effort should be exploited to do something none of us could do alone.

## Table 1. Summary of Participants' Statements

| Participant | Topic of Interest | Location | Facilities and Equipment |
|---|---|---|---|
| Akulichev, Russia | Acoustic monitoring of the ocean | Straits of Sea of Japan | Parametric source array<br>Various receiving arrays |
| Ali, USA (and on behalf of Apel, USA) | Internal wave generation and propagation in Northern South China Sea, acoustic and SAR studies | Northern South China Sea | SAR processing and analysis |
| Bulanov, Russia | Acoustic monitoring of small scale processes and features | South Sea of Japan<br>South China Sea | Parametric HF source arrays<br>Towed HF system |
| Chakraborty, India | HF bottom and sub-bottom interaction | South China Sea and adjoining areas | Data analysis and modeling |
| Chan, Singapore | Fronts, internal waves, tidal forcing and bubbles | South China Sea or other regions as appropriate | Numerical models, CTD, ADV, transmissometer, possible towed aqua-shuttle, remote-sensing support |
| Chinese Acousticians, China | Acoustic inversion for bottom parameters, reverberation, ambient noise, internal waves, currents and fronts, acoustic tomography | South Yellow Sea (33-34 °N,124-125 °E) | Research vessel, acoustic sources (broad and narrow band), three automated buoys, four vertical arrays, three thermistor chains, ADCP, CTD |
| Chinese Oceanographers, Qingdao | Acoustic studies in shallow water, shelf break, internal waves, fronts and eddies, strong forcing conditions | East China Sea shelf break region | Full compliment of modern oceanographic equipment, multi-beam sounder, and bottom sampling equipment |

**Table 1** (Continued)

| | | | |
|---|---|---|---|
| Chiu, USA | Pulse propagation studies, low-to-high frequency tomography, joint watercolumn and sediment inversions, horizontal coherence and 3D coupling, 3D reverberation, shelf dynamics, internal tides, internal wave dissipation | North shelf of South China Sea, East China Sea shelf, Yellow Sea | Tomography sources (400Hz), ADCP, Seacats |
| He, Qingdao, China | Multi-sensor studies of internal waves, observation and modeling of internal waves, generation and dissipation of internal waves in China seas | Yellow Sea<br>East China Sea<br>South China Sea | Historical SAR data from October, 1991, coincidental with field work, Landsat, SeaWIFS, and NSCAT data |
| Kaneko, Japan | Variability of strait throughflows, nonlinear internal waves | Luzon (Bashi) Strait, South China Sea, East China Sea | High frequency tomography systems, towed ADCP |
| Kuperman, USA | Spatial and temporal variability in signal and noise fields, self adaptive and focalization signal processing | Flexible, but needs remote sensing, shelf/slope site | Four 64 element arrays (450Hz), 64 element array (1 – 20 kHz), 24 element array (450 Hz), 20 element source array (3,500 Hz), array positioning system, thermistor chain |
| Kuryanov, Russia | Mesoscale interactions near the shelf break, internal waves | Flexible,<br>South China Sea | Autonomous systems with low frequency vertical arrays |
| Liu, USA | Sensitivity study of acoustic signals to internal wave evolution | Yellow Sea<br>South China Sea | Satellite remote sensing data (SAR, SPOT, IR, Ocean Color), possible research ship |
| Lynch, USA | Shelf/slope oceanographic processes, fronts, eddies, internal waves, ambient noise. Diversity of sources, receivers, and signals. | Northern South China Sea | A broad range of acoustic and oceanographic instrumentation and equipment |

**Table 1** (Continued)

| | | | |
|---|---|---|---|
| Na, Korea | Mixing processes between Kuroshio and shelf break possible due to internal waves, and tide. Acoustic signal fluctuations. | East China Sea | Research Vessel, CTD, ADCP, and other oceanographic instrumentation |
| Orr, USA | Broadband (10Hz – 10kHz) shallow water acoustic propagation (fluctuations, surface and bottom scattering) through random media (fronts, eddies, filaments, internal waves, and fine structure). Broadband shallow water noise, and near surface bubble distributions. | Yellow Sea, East China Sea, SW and NE Korea including Straits of Korea | Moored acoustic source, two or three 32 channel acoustic arrays (20Hz – 5kHz) with RF link, one 32 channel moored thermistor string, high frequency acoustic backscatter system, 32 – 64 channel towed thermistor string, 16-32 self recording temperature pods |
| Potter, Singapore | Small to medium scale ocean processes, bubble populations near surface, high-frequency tomography | South China Sea (<20 $^{o}$N) on continental shelf | Bottom-mounted data acquisition pods, autonomous profiling vehicles, remote sensing support |
| Ramp, USA | Continental shelf dynamics and acoustic propagation. | South China Sea (winter) | Current meters, releases, mooring gear and technology, CTD, ADCP |
| Worcester, USA (and on behalf of Cornuelle, USA) | Ocean variability caused internal tides, solibores, and shelfbreak front. Small-area, high-resolution moving ship tomography. | Flexible | 2-kHz sources, GPS receivers, pitch-roll-heave sensors, widely-spaced 10-element receiving arrays |
| Yamamoto, USA | Geo-acoustics, wave propagation in sediment and ocean, scattering from the seafloor, sediment properties | Japan Sea (western side) | Acoustic sources (100, 200, 400, 1000 Hz), 62 channel vertical array (600 m), recorders |

**Table 1** (Continued)

| | | | |
|---|---|---|---|
| Zhou, USA | Modal propagation in a shallow-water waveguide, reverberation, sea bottom acoustic inversion, signal space/time coherence | South eastern Yellow Sea off South Korea, East China Sea, South China Sea, Northern Sea of Japan | Broadband mode transmitting array |
| Unknown | Acoustic and oceanographic processes in the Tsashima Warm Current, mesoscale eddies, water mass formation, air-sea interaction in winter | Sea of Japan | Autonomous tomography sources and receivers, mooring system, ADCP, CTD, current meters |
| Unknown | Shelf break processes, bottom interaction, studies of the Kuroshio interaction | East China Sea<br>Sea of Japan<br>Yellow Sea | Research vessels, transmitting equipment (195dB, 500Hz-3kHz), Receiving and recording equipment |

# 6 Conclusions

The shopping list of processes and measurements of interest to the representatives was long and varied. In fact, it is probably impossible to list them all and do the particular ideas of each representative justice. In this concluding section of the workshop report, we attempt to capture the spirit of the discussions that took place during a closing session of the workshop that was led by Dr. Spindel of the Applied Physics Laboratory. This is pieced together from notes taken by Dr. Denner, and others.

What emerged was an interest in several possible experiments. It was decided not to let site location dominate the discussion, but the quality of the scientific effort. Possible sites in the South China Sea, East China Sea, Yellow Sea, Straits of Korea, and the Sea of Japan were discussed. The selection of the final site will be determined by the scientific program.

In general the focus was on a shelf or shelfbreak study. Several major themes to be incorporated in the collaborative international experiment were identified:

- Process oriented studies
- Acoustic tomography
- Small to mesoscale processes
- Fronts
- Eddies
- Internal waves
- Bubbles
- Seabed scattering and reverberation
- Noise
- Higher frequency and broader band sources
- Dense environmental sampling
- Use of remote sensing data, particularly SAR

The actual experimental design is something that we will wait to formulate in another workshop. However, some of the participants pointed out that the composition of the investigators and focus of the experimental work could change over the duration of the experiment. Furthermore, the site of the field effort could actually be moved during the course of the experiment.

Nearly all the participants expressed an interest in the possible collaborative experiment and had resources to contribute. While a site for the experiment was not selected at the meeting, several locations were proposed and discussed. The amount of observing systems available to the participants was formidable. Some participants expressed the need for additional tools. However, it is clear that a very well designed

experiment could be mounted, which would provide a wide range of observations on space and time scales that would be difficult for any individual country to achieve.

It was agreed that a second workshop would be held in June 1998, probably around the time of the International Acoustic Congress in Seattle, Washington. This would be a more focused workshop, with the development of a detailed experimental plan as its goal.

## 7 Acknowledgements

It is with great pleasure that we gratefully acknowledge the assistance of Bev Kuhn and Piper Magallanes in the organization, administration, and flawless execution of the Workshop. We also gratefully acknowledge Bob Spindel for leading the group discussions on the second day. Finally, the workshop would not have been possible without the creativity and financial support of Jeff Simmen of the Office of Naval Research as well as the enthusiastic participation of the delegations from the eight countries.

# Appendix A: Workshop Agenda

**Day One - December 8, 1997**

| | |
|---|---|
| 08:00-09:00 | Continental Breakfast |
| 09:00-09:10 | Opening and Administrative Remarks – Simmen/Livingston/Denner |
| 09:10-09:30 | Introduction of Participants, Institutions, and Current Research Interests |
| 09:30-10:00 | Strawman Scientific Issues – Chiu |
| 10:00-10:15 | Chinese Interests and Capabilities |
| 10:15-10:30 | Japanese Interests and Capabilities |
| 10:30-10:45 | Korean Interests and Capabilities |
| 10:45-11:00 | Break |
| 11:00-11:15 | Russian Interests and Capabilities |
| 11:15-11:30 | Singapore Interests and Capabilities |
| 11:30-11:45 | India Interests and Capabilities |
| 11:45-13:00 | Discussions |
| 13:00-14:00 | Lunch |
| 14:00-16:30 | Working Session – with break<br>-Definition of Scientific Issues and Interests |
| 17:30-18:30 | Reception |

**Day Two - December 9, 1997**

| | |
|---|---|
| 08:00-9:00 | Continental Breakfast |
| 09:00-09:30 | Summary of First Day Working Sessions – Chiu/Denner |
| 09:30-10:00 | Discussions |
| 10:00-13:00 | Working Session – with break |
| 13:00-14:00 | Lunch |
| 14:00-16:00 | Working Session – with break |
| 16:00-17:00 | Discussion and Wrap Up |

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